RF and Microwave in Bio-medical Applications

Xiue Bao, *Student Member, IEEE,* and Bart Nauwelaers, *Senior Member, IEEE*

***Abstract*—As reported in instructions of the congratulation letter, the awardees of the 2018 MTT-S Graduate Student Fellowship Awards should finish the Deliverables E. Therefore, herein we summarize the main outcomes of the project supported by the award.**

***Index Terms*—Analytic theories, device fabrication, platform improvement, spectroscopy measurements.**

I. Introduction

VERY important information on the composition and the living state of biological materials can be obtained from their broadband dielectric spectroscopy. In this project, we measured the dispersion of the liquids complex permittivity combining an interdigital capacitor that employs lumped circuit model and a coplanar waveguide transmission line that uses distributed circuit model. In order to increase the measurement accuracy, procedures including design optimization, device fabrication, platform improvement, first-tier Vector Network Analyzer (VNA) calibration, de-embedding algorithm, and control of the living materials environment are considered.

II. Outcomes of the Project

A. Device Fabrication and Platform Improvement

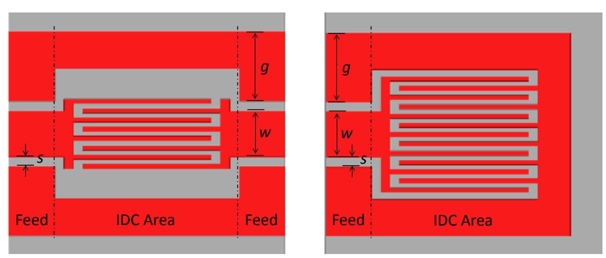
The combination of the microwave-based sensing technique with miniaturized microfluidic structures allows the application of the dielectric spectroscopy technique in handling, detecting, and quantifying microliter and even nanoliter volume of components, molecules, and living cell cultures at very low cost. The microwave microfluidic devices and sensors used in the project are mainly fabricated the lift-off techniques and etching methods developed in MEMS. Additionally, with the convenient availability of ESAT-CDE-CMW and KU Leuven FabLab, we also fabricate devices with non-cleanroom technologies, such as laser cutting method, 3D printing technique, casting approach, molding, etc. A large part of the budget was spent on the fabrication of the devices and test fixtures, including purchasing glass wafers, polymer materials, writing masks, fabricating, etc.

Biological materials, e.g., yeast cells and mammalian cells, need special environment requirements to stay alive and comfortable. These requirements include stable temperature, high humidity, certain CO2 content, and sterile environment. Therefore, the left part of the budget was mainly spent on building a platform that can be integrated with the microwave measurement system. First of all, a small incubator was purchased, to provide controllable environment for culturing and measuring living cells. It enables us better studying the cell performance and behaviors under a variety of conditions. In order to keep the pH values of the cell cultures, we also bought CO2 source and installed related gas controlling system.

X. Bao and B. Nauwelaers are with the TELEMIC Division of Department of Electrical Engineering (ESAT), KU Leuven, 3001, Leuven, Belgium. e-mail: xiue.bao@esat.kuleuven.be (see https://www.esat.kuleuven.be/telemic/People-of-telemic/00106873).

B. Analytic Theory for Device Design

Due to its non-invasive property, the interdigital capacitor (IDC) has been applied in dielectric liquid detection and characterization. In order to integrate the IDC sensor on a lab-on-chip, it is often required to minimize and optimize the sensor for sensitive and efficient performance. However, the conventional numerical simulation approach is quite time-consuming. Therefore, an efficient analytical method is proposed, leading to accurate capacitance and conductance expressions of an arbitrary multilayer-structured IDC. The model is validated with practical measurements of a series of coplanar waveguide (CPW) structure based IDCs, as shown in Fig. 1. Additionally, an accurate characterization function, which relates the IDC capacitance and conductance to the complex permittivity of a material loaded on top of the IDC sensing area, is obtained. The characterization function shows good agreement with finite element method (FEM) simulation results, which demonstrates the capability of the IDC sensor in dielectric spectroscopy measurements of μL and even nL liquids.



(a) (b)

Fig. 1: The schematic coplanar waveguide (CPW) structure based IDC sensors, showing: (a) top view of a two-port IDC and (b) top view of a one-port IDC

This work has been summarized as a journal paper named ”Modelling of Coplanar Interdigital Capacitor for Microwave Microfluidic Application” and has been submitted to the Transactions on Microwave Theory and Techniques.

C. Measurements and Analysis on Effective Permittivity

The use of dielectric spectroscopy is based on the assumption that the material under observation is homogeneous and isotropic, which is sometimes far from

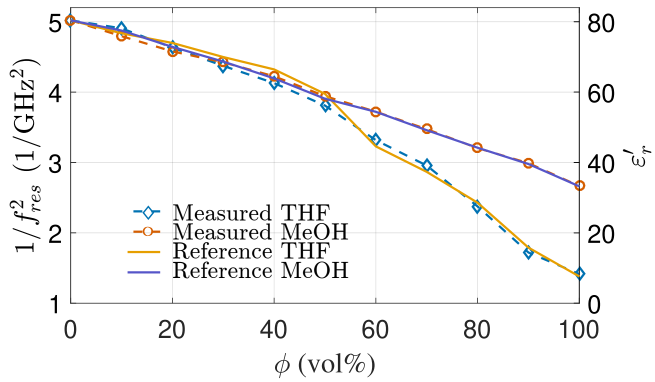


Fig. 2: Validation of the theory via the measurement results of water-methanol mixtures and water-THF mixtures.

the actual situation in cell cultures. To further describe the permittivity of mixtures, the effective medium approximation (EMA) is proposed, leading to many EMA models. The EMA models assume that inclusions or constituents are evenly distributed within a homogeneous system. They have been used to analyze heterogeneous media composed of two-phase and even multi-phase constituents, including composite materials, biological suspensions, and liquid mixtures. Nevertheless, applications of the EMA relations mainly focus on static permittivity analysis. In the project, the mixing theories of binary liquids are extended to radio frequencies and microwaves.

The project focuses on the measurement of effective permittivity of binary liquid mixtures using microwaves. A microwave microfluidic sensor for dielectric characterization of binary liquid mixtures is presented. The sensor is based on a split ring resonator and implemented in microstrip technology. The main advantage of this resonator-based approach is the high sensitivity and capability to detect small concentrations of inclusions in the media. After the validation measurements on pure liquids, a series of water-methanol mixtures and water-THF liquid mixtures with different concentrations are characterized with the proposed technique. As shown in Fig. 2, very good agreement between measurements and literature data was obtained. Then with the measurement results, mixing theories were considered.

This work has been summarized as a conference paper and a journal paper, intended to submit to the IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes 2019 conference (IMWS-AMP 2019) and the Transactions on Microwave Theory and Techniques, respectively.

III. Next Career Plans

For my ultimate career, I plan to be an academic researcher with microwave sensing technologies being my long-term research interests. I have gained extensive expertise in conventional microwave sensing methods on rigid substrate and I will extend the techniques to soft flexible materials in my next academic period, designing more efficient and effective microwave sensors. My strong background in microwave technology, device fabrication techniques, soft material handling, and biological material characterization makes me believe that I can offer a considerable potential in the field of flexible microwave sensors dedicated to measuring biological materials. During the project period, especially with the budget provided by the MTT-S Graduate Student Fellowship Awards, I gained the capability of handling multiple aspects of a project and tackling various research challenges. Attending the IMS conference helped me to know the state-of-the-art of the microwave sensing and stimulated many new ideas. I think these assets are essential in my future research program. As a creative and hard-working person with excellent research skills, I am sure I can carry out my research smoothly and successfully in the future.

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Xiue Bao (S'17) was born in Baoding, China. She received the B.Sc. degree in information engineering in 2011, and the M.Sc. degree in metallurgical engineering in 2013, in the University of Science and Technology Beijing, Beijing, China. She is currently pursuing the Ph.D. degree in electrical engineering at the University of Leuven, Leuven, Belgium. Her current research interests focus on microwave biomedical applications, including broadband dielectric spectroscopy; biosensor design; microwave-microfluidic structure design and fabrication; RF, microwave, and millimeter wave measurement and calibration. She was one of the recipient of the IEEE Microwave Theory and Techniques Society Graduate Student Fellowship in 2018.

Bart Nauwelaers (S'80-M'86-SM'99) received the Ph.D. degree in Electrical Engineering from the KU Leuven in 1988. He also received the Master's degree in Design of Telecommunication Systems from Telecom ParisTech, Paris, France. Since 1981, he has been with the Department of Electrical Engineering, KU Leuven, where he has been involved in research on microwave antennas, passive components, interconnects, microwave integrated circuits and MMICs, linear and nonlinear device modeling, MEMS, and wireless communications. Prof. Nauwelaers is the former chair of IEEE AP/MTT-Benelux and past chair of URSI-Benelux.